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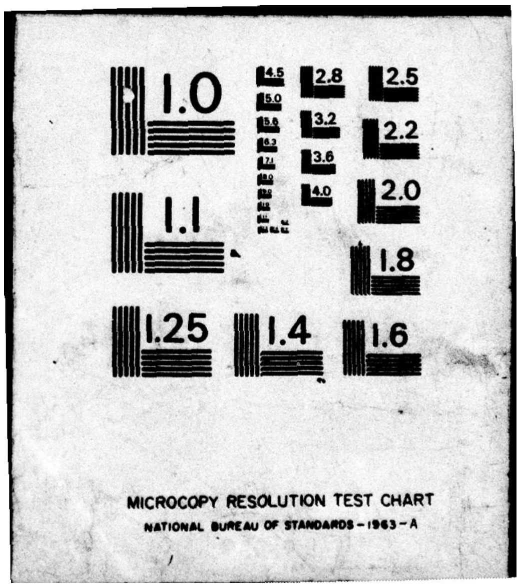
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ENERGY CONSERVATION IN BUILDINGS

C. Burgess Ledbetter

December 1976

CORPS OF ENGINEERS, U.S. ARMY
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This report scans current building designs and describes, for the layman, ways that buildings could be designed for improved energy consumption. Topics of building design addressed are insulation, thermal bridges, ventilation, orientation, lighting, windows, and solar heat.

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Energy Conservation in Buildings

C. Burgess Ledbetter

September 1976

PREFACE

This report was prepared by C. Burgess Ledbetter, Research Architect, of the Applied Research Branch, Experimental Engineering Division, U. S. Army Cold Regions Research and Engineering Laboratory. Funding was provided by DA Project 4A762719AT06, Military Construction and Maintenance in Cold Regions, Task 01, Cold Regions Facilities Operations, Maintenance, and Engineering in Cold Regions, Work Unit 003, Habitability Criteria for Military Installations in Cold Regions.

Dr. H.W.C. Aamot technically reviewed the manuscript.

INTRODUCTION

Approximately 14% of the annual total energy used in the continental United States is consumed in the operation of commercial buildings. The total approximates 33%, if residential consumption of energy for space heating and cooling, lighting, cooking, refrigeration and the operation of small appliances is added. Transportation of people and goods and industrial uses of energy account for the remaining 67%. In addition fossil fuels, which supply most of these energy needs, are also needed as raw materials for the manufacture of plastics and asphalt, much of which is used in construction. It is interesting to note that fossil fuels are used more advantageously to produce plastic insulating materials than to burn for heating of buildings.

Architects and engineers have precise methods of influencing the energy consumption of buildings. Sophisticated heat flow calculations can be made, and a broad range of building materials and heating, ventilating and air conditioning equipment can be used for achieving desired conditions. The General Services Administration and Public Building Service recommend that calcualtions for thermal control systems of buildings in excess of 20,000 ft^2 utilize only computer analysis and only computer programs that address dynamic thermal flow.

Designing thermal regimes for sensitive equipment such as computers and reproduction equipment is very exacting. Humidity, air cleanliness and temperature limits are narrow, but the equipment is usually located in small, stable interior areas of buildings. Designing thermal regimes for people can be less exacting in terms of the range of temperature, cleanliness and humidity boundaries but is significantly complicated by windows, exterior walls and lighting.

Designing thermal regimes at the boundaries of comfort established by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) and consistent with the climatic conditions and seasons can save energy. For example, a 3% reduction in heating energy can be realized for every one degree the thermostat temperature is reduced when the outdoor temperature is 40°F. On a summer day with outdoor relative humidity of 50%, approximately 30% more cooling energy is required to maintain 50% rather than 60% indoor relative humidity.

Wise use of these thermal boundaries, however, must be recognized. Moderately hot conditions increase susceptibility to intestinal disease and moderately cold conditions increase susceptibility to respiratory disease. Motivation and performance of employees can decrease if they perceive that management is allowing them to be uncomfortable simply to save money. People can tolerate greater extremes of temperature and humidity in corridors than in offices and shops where they are more sedentary. Clothing, whether prescribed as uniforms for school gym classes and troops or inferred as for offices, can be adapted to account for broader extremes of the thermal comfort range.

Within facilities, there are almost endless examples in which energy can be better conserved. Measures could be taken which affect the users directly. For example, use of black felt tip pens on lightly tinted paper would allow for approximately a 40% reduction in lighting compared to using no. 2 pencils on white paper (in Energy Conservation Design for Office Buildings by GSA/PBS, 1974).

For this discussion of energy consumption the following aspects of facilities are briefly discussed:

a. Insulation
b. Thermal bridges
c. Ventilation
d. Orientation
e. Lighting
f. Windows and solar heat.

Only highlights of each aspect are cited and by no means are these areas covered completely nor are all aspects of facilities which contribute to energy consumption included.

a. Insulation. If all homes in the U.S. were fully insulated, energy for residential heating would be reduced by approximately 42%. By adding 1 inch of insulation to a typical wall with 2 1/2 inches of glass fiber insulation, conductive heat loss would be reduced by 21%.

The basic insulation materials are*:

Mineral fibrous - asbestos, rock, slag and glass wool

*From Callender, Time-Saver Standards for Architectural Design Data, McGraw Hill, 1974.

Flexibility or semirigid - blankets and batts of wool-like material
Rigid - boards and blocks
Membrane - reflective insulation
Spray applied - mineral fiber or insulating concrete
Poured in place - insulating concrete
Foamed in place - polyurethane.

In addition, wood, soil and encapsulated air spaces act as insulators in certain applications. Tables are available for calculating thermal conductivity of most materials used in construction.

The effectiveness of insulation can be significantly influenced by construction details. For example air pressure differences can cause air to flow through the insulation, and water or water vapor can penetrate the insulation, all of which reduce its thermal resistance. Vapor barriers in buildings are seldom found intact following construction and use. Gaps in the barrier, barriers on the wrong side of the insulation, nail holes and other penetrations short-circuit the vapor barrier and let moisture enter. Technology for proper vapor control is available but accidents, construction short-cuts, inadequate inspection and designers unfamiliar with details for differing climatic conditions account for unknown quantities of fuel to be expended needlessly, not to mention the rapid deterioration of the structures.

b. <u>Thermal Bridges</u>. "Thermal bridges" short-circuit insulation and contribute to heat loss (winter) and heat gain (summer) thus nullifying the effect of insulation. These bridges are details of walks, roofs and windows which contain construction materials that conduct heat readily and penetrate through the building envelope from the interior thermal regime to the outside. In the north during winter these bridges become obvious, as condensation will appear on the inside surfaces of the material. The condensation will often contribute to deterioration of the construction materials, but more importantly energy is consumed to replace the heat lost in winter and to remove the heat gained in summer.

Often for esthetics, fins or extensions of floor slabs or partitions are displayed on the exterior of buildings. While their only functional purpose may be to shade windows from solar heat, they are often extended on all sides of a building for appearance. These fins act as radiators, increasing the surface area of a building and often acting as thermal bridges if not isolated from the building interior by insulating materials.

The shape of a building also determines the surface area of the outside walls and roof which is related to heat flow. For example, at a

constant volume of 1,000,000 ft^3 and gross floor area of 100,000 ft^2 the following surface areas result as a function of shape:

a. 40 story building 50 ft on a side exposes a total surface area of 85,000 ft^2.

b. 5 story building 100 ft by 200 ft exposes a total surface area of 70,000 ft^2.

c. 10 story building 100 ft on a side exposes a total surface area of 50,000 ft^2.

c. <u>Ventilation</u>. Ventilation of buildings poses some paradoxes. In hospitals from six to twelve air changes per hour are required. In such a situation, the air that architects and engineers were formerly trying to get rid of can be easier to clean than the outside "fresh" air.

For many buildings the heat loss associated with ventilation and air filtration through windows, doors and other unsealed penetrations is of about the same magnitude as the heat lost by conduction through the building envelope. However, complete sealing of all openings should not be overdone, for a fresh supply of air equivalent to a minimum of one air change every two hours is required to control odors and prevent stuffiness. A heat exchanger can reduce the heat normally lost through discharge of stale air by 50%. This heat is transferred from the warm exhaust air to the cool fresh air entering the building.

Buildings in climates normally requiring air conditioning, but which for economic reasons do not have air conditioning, should be designed to minimize solar and building equipment heat gains. Such buildings require high rates of ventilation, with as many as 30 or more air changes per hour. Flow of air past the occupants also provides relief by increasing convective heat losses. Large operable windows which are shaded from the sun are best for such ventilation. Clean outside air must be available since filtering is difficult. Because the air flows across a building or up through stack or chimney effects, smoke and fire spread must be considered.

d. <u>Orientation</u>. Orientation of a building contributes significantly to energy use. Frank Bridges, past president of ASHRAE, cites the following example.* If a rectangular buildings, 2 1/2 times longer than it is wide and oriented east-west with 50% glass, is turned 90°, the following benefit is derived. By changing to a north-south orientation the cooling load is reduced by 30%, which is only 50% more load

*Architectural Record, January 1972.

than if the building had no windows at all. An additional 25% savings can be obtained if shade trees surround the building.

Trees and grass absorb sunlight and convert a large portion of heat into other forms of energy. For comparison, temperatures taken over asphalt in sunlight were 125°F and over a nearby shaded area of grass 98°F.* Shaded grass areas adjacent to buildings rather than asphalt drives and parking lots would reduce heet gain. Glare, dust and noise would also be reduced.

A shelter belt of trees can reduce wind velocities by 50% and has been demonstrated to reduce heating fuel consumption in farmhouses in lee of the trees by 30%. Wind breaks, whether natural of manmade, should be considered an essential tool of thermal design.

e. Lighting. Reducing the power drawn by lights has a double effect: energy for air conditioning and for operating the lights is reduced. Waste heat is a by-product of illumination; that is, a 100-watt light bulb produces 100 watts of heat. In a space with 100 foot-candles illumination (that recommended for reading tasks of average printing on poor paper) waste heat can account for 37% of the summer cooling load. If the illumination is raised to 400 foot-candles as is sometimes found in drafting rooms - by comparison 2,500 fc's are required for a hospital operating table - the factor will rise to 70% of the summer cooling load. To reduce the heat load, the heat from lighting can be shunted out of the building before it reaches the occupied areas. Less than 1/2 of the heat produced by fluorescent lamps is radiant whereas 3/4 from incandescent or filament lamps is radiant. Since fluorescent bulbs provide two to four times as much light per watt of electricity as incandescent bulbs, radiant heat of fluorescent lamps, for equal illumination, is approximately 1/5 that of incandescent.

Other sources of light are the high-intensity discharge lamps: mercury, metal halide and high pressure sodium. Because of the high intensity from a point source and noisy ballasts, these lamps are not used for office-type lighting.

The efficiency of lamps in terms of lumens per watt is as follows:

incandescent	8-22 lumens/watt
fluorescent	79 lumens/watt
mercury	30-65 lumens/watt
metal halide	70-95 lumens/watt
high pressure sodium	110 lumens/watt

*Finch, American Building 2, Houghton Mifflin, 1972.

Without a change in lighting, light-colored reflecting surfaces such as walls, ceilings and floors can increase illumination as much as 30 foot-candles, as compared to dark surfaces. Only 5% to 10% of normal lighting intensity can be sufficient for nighttime cleaning and security. Specific tasks requiring high intensity lighting such as drafting can be "task lighted" as opposed to maintaining an overall high illumination in the general area.

f. Windows and Solar Heat. A single pane of glass resists heat transfer on the order of one unit compared to 10 units for an insulated wall. Ordinary double-glazed windows have a resistance of about two units and some heat reflecting double-glazed units have over three units of resistance. Due to solar heat gain, a double-glazed window on the south wall of a building as far north as Canada can have about the same net heat loss over a full heating season as an equal area of insulated wall. Thermal efficiency of buildings totally encased in glass has yet to be shown.

Often windows are encased in an aluminum frame. Twenty-five per cent of heat lost through such a metal framed window occurs through the frame where as only 13% is lost through a wood frame. A 10-ft^2 aluminum framed window facing south (the best of orientations) can lose as much as 425 Btu per day in winter. Thermal breaks of a low conductivity material are provided in some metal window casings, significantly reducing the thermal bridge.

Not only is heat transferred through the casement thermal bridge but is transferred through air leakage. In a typical office building designed for air conditioning, with loose fitting double windows that cover 30% of the exterior wall area, 45% of wall heat gain in summer and 60% of wall heat loss in winter occur from air leakage. These figures are reduced to 4% and 8%, respectively, if these windows are tight fitting.

Extra layers of glass can be provided in the form of removable storm windows or permanent installation. Most popular are the sealed glazing units of usually no more than two layers of glass. Besides reducing heat flow, their advantages are:

a. No condensation between glass (not fool-proof)
b. Simplification of design
c. Reduced number of surfaces requiring cleaning.

These windows are hermetically sealed and are available with a choice of three types of spacers:

a. Lead
b. All glass edge
c. Sealed with a spacer filled with a desiccant.

In most parts of the country, in the summer, approximately a ton of cooling capacity is required for every 100 ft^2 of exposed glass on the east or west of a building due to solar load. Windows on the north of a building (excluding winter) and in all cases the south side of the building (if windows are shaded) are most desirable.

Windows of any appreciable size in east, west and south walls must be shaded. Glass can be tilted out at the top. Glass tilted at 78° reflects 45% of radiation compared with 23% when the glass is vertical. For an 8-ft piece of glass, this tilt has the same effect as a 16-in. shade projected above the window.

From mid-March to mid-September a south facing window can be completely shaded by an overhead projection just a little shorter than the height of the window. Such a window facing only 30° from south toward either the east or west would require an overhead projection more tha[illegible] twice the height of the window to be shaded. Venetian blinds prov[illegible] the same shade effect as a building projection. However, since the blind is often on the interior of the building, the heat absorbed remains inside. For example, a light-colored Venetian blind set at a 20° slant absorbs about half of the direct solar radiation falling on it, transmitting this heat to the interior, and reflects only about 35% to the outside. The advantage of placing the shade between pairs of sealed glass is obvious since less heat is transmitted to the interior. Attempts have been made to install adjustable horizontal and vertical fins on the exterior of buildings to shade both windows and walls but maintenance is high and ice seriously disrupts its service.

Glass can be tinted (often called heat absorbent) or reflective-coated to reduce solar transmission, reducing glare and radiant heat. From "Time-Saver Standards for Architectural Design Data," the following types of glass and their effects on solar load in percentage reduction in solar load per square foot are given:

	% reduction in solar load per ft^2
Single clear plate 1/4 in.	0
Double clear plate, 1/2-in. air space	22
Single heat absorbent without inside shade	47
Double, 1 clear plate and 1 heat absorbent with air space	55
Double coated glass	70
Double clear plate with Venetian blind in air space	70

Still in developmental stage is a photo chromatic glass which reacts reversibly to the ultraviolet in sunlight. It becomes darker as more ultraviolet falls upon it. At present it is too expensive for commercial use except in such applications as eye glasses and other special uses.

It should be noted that a room designed to take full advantage of daylight does not necessarily result in a higher heat gain than a windowless room with artificial light. Parodoxically, the greater the intensity of solar light falling on an object, the greater the need to brighten all other objects in the general area to reduce glare.

CONCLUSION

It can be seen that much can be done in the field of architecture and engineering of buildings to conserve energy. During these years of political, economic and engineering struggle to provide effective means of producing energy, it will be advantageous to emphasize conservation of energy needlessly wasted in architectural structures. At least one reason for considering energy conservation in building design is because it can produce money savings (reducing the the cost of ownership). Life cycle cost analyses will determine the cost effective level of energy conservation. One must only resolve the question of whether to use past, present or future costs of energy in the analysis!